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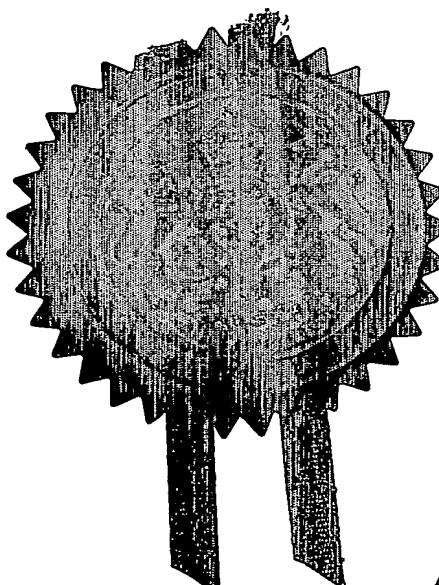
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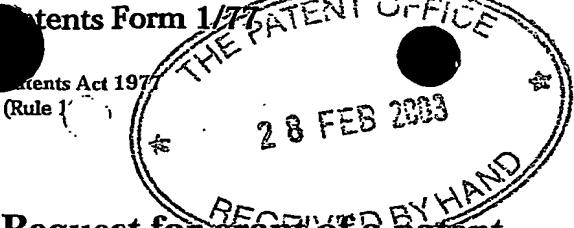
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Dated 27 May 2003



The  
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177

## Request for grant of a patent

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The Patent Office

Cardiff Road  
Newport  
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NP9 1RH

### 1. Your reference

ABC/21455

### 2. Patent application number

(The Patent Office will fill in this part)

0304667.9

03MAR03 E768322-4 000180  
P01/7700 0.00-0304667.9

### 3. Full name, address and postcode of the or of each applicant (*underline all surnames*)

PBT (IP) Limited

1 Astra Centre  
Edinburgh Way  
Harlow  
Essex  
CM20 2BN  
United Kingdom

7645336001

### 4. Title of the invention

CONTROL ARRANGEMENT FOR A PIEZO CERAMIC ACTUATOR

### 5. Name of your agent (*if you have one*)

A A Thornton & Co

235 High Holborn  
London  
WC1V 7LE

Patents ADP number (*if you know it*)

75001

### 6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (*if you know it*) the or each application number

Country

Priority application number  
(*if you know it*)

Date of filing  
(day / month / year)

### 7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing  
(day / month / year)

### 8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

yes

- a) any applicant named in part 3 is not an inventor, or
  - b) there is an inventor who is not named as an applicant, or
  - c) any named applicant is a corporate body.
- See note (d)*

Patents Form 1/77

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Continuation sheets of this form

Description 4

Claim(s) 1

Abstract 1

Drawing(s) 1 *x*

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (*Patents Form 7/77*)

1

Request for preliminary examination and search (*Patents Form 9/77*)

Request for substantive examination  
(*Patents Form 10/77*)

Any other documents  
(please specify)

11.

I/We request the grant of a patent on the basis of this application.

Signature

Date

*[Handwritten Signature]* 28 Feb 2003

12. Name and daytime telephone number of person to contact in the United Kingdom

Andrew B Crawford - 020 7405 4044

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DUPPLICATE

1

CONTROL ARRANGEMENT FOR A PIEZO CERAMIC ACTUATOR

The present invention relates to piezo ceramic actuators and more particularly to a control arrangement for such an actuator. A piezo ceramic actuator consists of a metal substrate to which a ceramic plate is bonded. A simple and effective actuator is in the form of a planar substrate provided with a slit extending from one edge and parallel to the adjacent edges to form two parallel legs joined by a bight. The ceramic material is then applied to the legs. As is common with most types of actuators, it is necessary that a piezo ceramic actuator operates reliably across a wide temperature range. As a result, metal substrate is manufactured from a carefully selected controlled expansion alloy to ensure optimum thermal stability for the required application. However, the complex thermal behaviour of the piezo ceramic material can often severely limit the performance of the actuator leading to increased cost and complexity as well as reliability issues.

Not only do the basic piezo electric parameters vary with temperature, but a dominant effect is the rapid increase in the histeresis as the temperature reduces. This is especially true for the very active soft ceramic materials used to provide maximum performance from the actuator.

One method for improving performance at lower temperatures is to apply a field to the ceramic material in the opposite direction to the polarisation of the ceramic material. This reduces the remnant polarisation resulting in a significant increase in the working stroke of the actuator and also improves thermal stability. The reverse field, however, must be maintained below the coercive field strength of the material. If the coercive field is exceeded, then rapid reversal of the polarisation direction occurs. This will reverse the direction of movement of the actuator in response to the applied control signal resulting in inverse movement of

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the actuator. The correct polarisation can be recovered, but only by exceeding the coercive field, applied this time in the new "reverse" direction.

The coercive field strength is highly temperature dependent, decreasing as the temperature increases to approach 0 at the Curie temperature of the material.

- 5 Not only does the coercive field vary with temperature, but also the relationship between position and applied charge or voltage is also temperature dependent. This can result in a large variation in speed of response with temperature. This can lead to poor stability in control systems and temperature dependent performance in applications such as piezo speakers where control of the speed of  
10 the diaphragm is critical.

The present invention provides a control arrangement for adjusting the control regime of a piezo ceramic actuator in response to temperature variations.

- Preferably, the control arrangement incorporates a micro-controller which applies a temperature variable reverse field and charge rate to the actuator. This  
15 system substantially improves performance at low temperatures. In fact, the actuator force and deflection increases as the temperature decreases. Using this technique, actuator deflection was found to be improved by a factor of over 3.5 at low temperatures. The range of positions accessible to the actuator across a temperature range is also improved nearly 3-fold. This improves tolerance to  
20 variations in position of both the actuator and the mechanism being actuated. This can lead to cost benefits through the use of lower precision manufacturing and assembly techniques.

In order that the present invention be more readily understood, an embodiment thereof will now be described with reference to the accompanying drawings in which:-  
25

Fig 1 shows a block diagram of a control arrangement according to the present invention;

Fig 2 shows a waveform diagram of the high voltage rail during a charge forward/reverse cycle; and

Fig 3 shows a diagram showing the variation of forward and reverse positions of an actuator with temperature.

Referring now to Fig 1, a piezo ceramic actuator 10 is connected to a drive circuit in the form of an H-bridge 11 to which a voltage is supplied from a power supply unit 12. The unit 12 is preferably a variable high voltage source driven from a low voltage source 14 eg 12 volt supply using a controller unit 15. The controller unit 15 also contains an H-bridge control circuit which is connected to the H-bridge 11 and is responsive to signals from a temperature sensor 16 closely associated with the actuator 10.

The H-bridge 11 applies a reverse voltage to the piezo ceramic actuator 10 at constant current. The value of the reverse voltage is controlled by the control circuit in the controller unit 15 in response to signals from the temperature sensor 16. The average charge current is also controlled by the control circuit.

There is a very nearly linear relationship between coercive voltage and temperature in the range -25°C to +25°C as the coercive voltage falls from 270 volts to 80 volts. This is used to apply a very simple algorithm for the control of the reverse voltage. A margin is built in to ensure operation well below the coercive voltage. The forward voltage is maintained at between 400 volts and 500 volts throughout the temperature range. This is shown in Fig 2.

With the above arrangement, an almost constant linear charge rate can be obtained from most of the charge/discharge operation. The benefits of the control system are apparent from Fig 3 which shows the variation in actuator position with temperature under differing conditions. It also shows the actuator positions during the discharge parts of the angle both from a forward position and a reverse position. The discharge from forward position will correspond approximately to

the position reached without reverse biased being applied, ie in "unipolar" mode.

It is clear that without reverse bias the performance across the full temperature range is compromised. This is indicated by the different between the arrows a and b.

5 It will be appreciated that when the above control arrangement is utilised with an actuator whose materials and manufacturing method have been selected in order to provide optimum mechanical thermal expansion properties, considerable advantages can be obtained.

## CLAIMS:

1. A control circuit for controlling the operation of a piezo ceramic actuator comprising means for applying a reverse bias voltage to a piezo ceramic actuator,  
5 means for generating a control signal indicative of the temperature of the actuator and means for altering the amount of reverse bias voltage as a function of the control signal.
2. A control circuit according to claim 1, wherein the means for applying a  
10 reverse bias voltage includes an H-bridge.
3. A piezo ceramic actuator arrangement comprising a piezo ceramic actuator and a control circuit according to claim 1 or 2.

ABSTRACT

A control circuit for controlling the operation of a piezo ceramic actuator comprises means for applying a reverse bias voltage to a piezo ceramic actuator,  
5 means for generating a control signal indicative of the temperature of the actuator and means for altering the amount of reverse bias voltage as a function of the control signal.

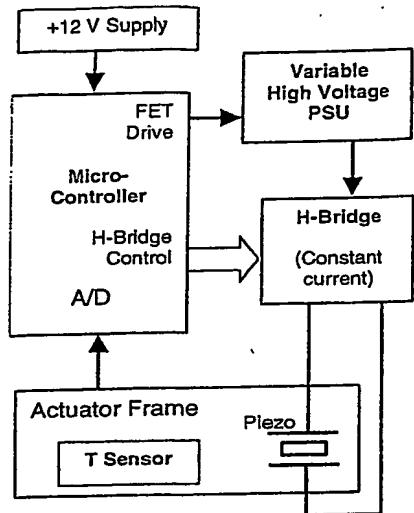


FIG. 1.

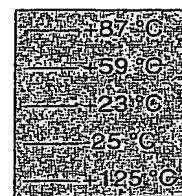
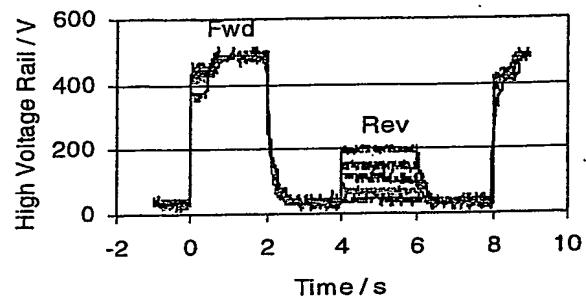


FIG. 2.

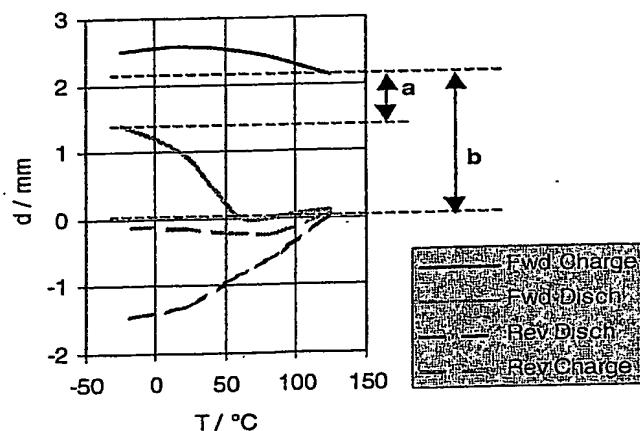


FIG. 3

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